# ORDERING SHELTER OR EVACUATION DURING AN OUTDOOR TOXIC GAS RELEASE INCIDENT: THE C.A.F.C. DECISION FLOW CHART

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**ABSTRACT**

The technical basis used to develop the proposed CAFC decision chart for ordering shelter-in-place or evacuation of people during an outdoor toxic gas release is presented. The chart asks simple questions with yes or no answers to help make the initial decision to shelter-in-place or evacuate. The most important feature of the decision flow chart is that the decision to keep people sheltering-in-place is reviewed at regular intervals (usually 1 hour) during the incident. The definition of Aadequate protection from shelter-in-place@ still needs to be refined by training of first responders and by documenting their experience in actual incidents.

**THE SHELTER OR EVACUATE DECISION FLOW CHART**

The former Major Industrial Accident Coordinating Council of Canada (MIACC) initiated the process of developing an evacuate or shelter decision flow chart. The task force that started this evolutionary process is listed in the proposed CAFC Guide , and in the Acknowledgments section of our paper.

The flow chart in Figure 1 relies on the definitions of the AInitial Isolation Zone@ and AProtective Action Zone@ in Figure 2 taken from the Emergency Response Guide (2000). The sizes of these zones depend on the type and quantity of the substance that is spilled or released, as given in the Guide.

The major features of the proposed CAFC flow chart are:

$ Evacuation of the Initial Isolation Zone is the always the best choice.

$ Shelter-in-place is always the first option in the Protective Action Zone.

$ In the Protective Action Zone no evacuation would ever be attempted as long as shelter-in-place continues to provide Aadequate@ protection.

$ The decision steps are made by simple yes/no answers to questions.

$ The decision to order an evacuation is made only after evaluating the effectiveness of shelter indoors.

$ The decision to keep people sheltering-in-place must be reviewed at regular intervals (usually 1 hour) during the incident.

$ Choosing an effective building shelter effectiveness review time of 1 hour on the flow chart is a conservative estimate that covers many typical Canadian building and weather situations.

$ For highly toxic gases and large rates of release this review time interval would be reduced to as periods as short as 15 minutes.

**ASupervised evacuation@** is defined as an evacuation in which assigned response personnel are responsible for warning people in the area(s) to be evacuated about the specific nature of the hazardous release, instructing them in methods and routes for safe evacuation to designated waiting locations, and providing the evacuees with movement assistance.

**AAdequate protection from shelter-in-place@** is tentatively defined as implying that people sheltering in a particular building are not exhibiting symptoms that require immediate medical care by trained medical personnel or by first responders. The people in shelter may smell the gas and feel some effects that are not an immediate danger to life or health.

At present, the choice of a 1 hour reassessment interval for checking the effectiveness of sheltering is conservative, considering the low infiltration leakage rates into most Canadian buildings, as shown in Figure 3 from Wilson (1996).

## ESTIMATING THE EFFECTIVE PROTECTION TIME OF A BUILDING

To make use of the flow chart the incident commander must be able to answer the question AIs shelter-in-place still providing effective protection?@ There is no easy way for a first responder to answer this question. The answer depends on three factors, the air infiltration time constant of the building, the average outdoor atmospheric concentration around the building, and concentration fluctuations during the event.

### Factor 1: Air Infiltration Time Constant

The effective protection time is proportional to the building air infiltration time constant. The air infiltration time constant of the building in hours is defined as the time the well-mixed indoor concentration will rise to 63% of the outdoor concentration. This time constant is just the inverse the outdoor air infiltration rate expressed in building volume air changes per hour (ACH), that is

$$\text{(Air Infiltration Time Constant hrs)} = \frac{1}{\text{(Air Changes per Hour)}}$$

The air infiltration time constant $(ACH)^{-1}$ can vary by a factor of 10 or more, depending on whether it is

- cold or hot outdoors
- windy or calm weather,
- dense or sparse building spacing (for wind sheltering),
- commercial or residential buildings,
- mechanical (fan) ventilated or naturally ventilated buildings,
- leaky old or tight new construction.

Table 1, from Wilson and Walker (1992), shows that for a typical Canadian bungalow with a full basement, changes in weather can increase the natural air infiltration rate from 0.10 ACH (air changes per hour) to 0.68 ACH. So, in this case the effective air infiltration time constant varies from 10.0 hours in summer with light winds to 1.5 hours in winter with strong winds.

There are simple equations for predicting the effect of changing weather on the natural air infiltration rate into buildings, see Walker and Wilson (1998). All that is needed is the infiltration rate at a known wind speed and indoor-outdoor temperature difference. Unfortunately, this baseline infiltration rate is very difficult to estimate just by looking at a building, and first responders must rely on a best guess based on statistics.

### Factor 2: Average Outdoor Concentration of the Toxic Gas

The average outdoor atmospheric concentration C of the toxic gas that is infiltrating into the building depends on the ability of the atmosphere to disperse the gas as it is carried downwind. For an unignited ground level release with no buoyant plume rise,

$$\text{(Outdoor Concentration ppm)} = \frac{\text{(Dispersive Ability) (Rate of Release } m^3/s)}{\text{(Wind Speed m/s) (Downwind Distance m)}^2}$$

Note the squared dependence on downwind distance. The ADispersive Ability@ of the atmosphere is a factor that is a constant for the set of weather conditions that apply to a specific toxic release incident.

The ADispersive Ability@ of the atmosphere can vary by a factor of 100 or more, depending on whether the toxic release occurs when it is

$ day or night
$ cloudy or sunny
$ winter (snow) or summer (vegetation/asphalt)
$ urban (rough) or rural (smooth) terrain

Average outdoor concentrations are estimated using atmospheric dispersion equations that quantify the highly variable dispersive ability of the wind for and average of many identical release events.

**Factor 3: Concentration Fluctuations During a Toxic Gas Release**
Wilson (1986,1991) pointed out that one of the major benefits of shelter-in-place is that the large naturally-occurring concentration fluctuations that occur outdoors are removed by the mixing that occurs inside a building. People exposed indoors are protected from the large momentary outdoor peak concentrations.

New techniques for realistic computer simulation of these outdoor and indoor concentration fluctuations are being developed, see Wilson (1995) and Hilderman and Wilson (1999). Combined with the model of Hilderman, Hrudey and Wilson (1998) for the biological toxic load caused by concentration peaks, the advantages of shelter-in-place have been quantified. These new computer simulation techniques for real-time concentration fluctuations have the potential to be a powerful training tool for first responders.

Figure 4 shows these new techniques being applied to the simulation of worst case events (100% fatalities outdoors) and best case (0% fatalities outdoors) events in an ensemble of 100 random repeats of a toxic release incident where a neutrally buoyant mixture of 25% volume fraction of hydrogen sulphide is released over a period of 30 minutes from a pipeline rupture in a rural area. Two different weather conditions are shown: a sunny summer day (Class A stability), and a clear, cold , winter night (Class F stability) both with a 11 km/h wind speed at the nearby airport.

In the simulation, people are sheltered indoors in a leaky building that has an air infiltration rate of 1.0 air changes per hour, giving it a air infiltration time constant of 1.0 hour. The buildings are 100m downwind for the summer day release, and 1000m downwind for the winter night release. These distances were chosen to produce high average outdoor fatalities for the 30 minute outdoor exposures.

The results are a clear indication of the protection provided by shelter-in-place, with the worst case events producing 100% fatalities for people exposed outdoors for 30 minutes, and 0% fatalities for people sheltering indoors for 30 minutes. The main advantage of sheltering was avoiding exposure to the large outdoor concentration fluctuations during the incident.

## INCREASING THE EFFECTIVE PROTECTION TIME OF A BUILDING
The effective shelter protection time after the toxic cloud arrives at the building can vary from about 15 minutes to about 4 hours. Choosing an effective shelter protection time of 1 hr on the CAFC flow chart is simply a reasonable estimate that covers most typical situations.

There are many protective actions that will help improve the effective air infiltration time constant of a building. Some of these, such as taping the cracks around a window, may provide only a small increase in protection time. Here, we will focus on a few of the most effective actions. For a more extensive list, see Blewett et al (1996).

**Protective Actions in All Buildings**
In all buildings, windows, doors and fireplace dampers should be tightly closed. Clothes dryers, and

kitchen and bathroom ventilation fans should not be turned on. Begin sheltering with as many internal doors closed as possible. Choose a Asafe-haven room@ where you will be comfortable, and have access to a radio and telephone. If possible choose this safe-haven on the side of the building away from the direction of the toxic gas release. If you don=t know where the release is coming from, choose a room on the downwind side of the building.

**Protective Actions in Mechanically (Fan) Ventilated Buildings**

In mechanically (fan) ventilated buildings such as retail stores, offices, hospitals or schools most of the outdoor air is brought in through air intake louvers on equipment rooms, or on roof-mounted heating/cooling units.

When sheltering-in-place in these types of buildings, the outdoor air intake dampers should be closed and the ventilation system set to use 100% recirculated air. Shutting off the outdoor air intakes will increase the effective protection time of a fan ventilated building; often by factors of 2 or more.

**Protective Actions in Naturally (Wind) Ventilated Buildings**

In a naturally ventilated building such as a house, most of the outdoor air enters the building through leakage sites such as cracks around doors, windows, plumbing pipes, furnace and fireplace flues, and where the walls meet the foundation.

In these buildings, wall or window mounted air conditioning units and fans should be turned off, and their openings sealed by closing a damper (if they are so equipped), and taping a plastic bag over them. Thermostats on central heating and air conditioning systems should be adjusted to minimize the on-time of the unit. In winter, set the heat thermostat to 10C and in summer set the air conditioner thermostat to 30C. With these measures the effective protection time can be extended; often by a factor of 1.5 or more.

## MINIMUM AIR INFILTRATION TIME CONSTANTS FOR VERY LEAKY BUILDINGS

Wilson (1996) estimated the building air infiltration time constant of the leakiest one percentile of naturally and mechanically ventilated buildings likely to be found in Canada and in the USA. These values apply to buildings with all exterior doors and windows tightly closed, and heating and ventilation fans turned off.

Figure 5, taken from Wilson (1996) shows that we can expect a building air infiltration time constant of about 0.7 hours for the 1-in-100 leakiest building. That is, less than 1% of buildings are expected to be leakier than this case. Keep in mind that the air infiltration time constant can increase and decrease by about a factor of 3 depending on indoor-outdoor temperature and the wind speed, as shown in Figure 3.

## TOXIC vs FLAMMABLE GASES

Should people be advised to shelter inside a building when there is a flammable or explosive spill somewhere outside the building? Currently the CAFC Guide and Flow Chart recommends evacuation in all situations involving flammable or explosive material. The LPG association in their training materials always recommend evacuation, due to the potential of a BLEVE.

In our view, the Aevacuate if flammable@ policy may not always be right. Do first responders really want people running around outdoors when the flammable/explosive material is also outdoors? For example, how could first responders safely evacuate an area such as downtown Toronto in the middle of a business day? In reality, rapid evacuation is only feasible if the release occurs in an open uncrowded area. We believe that the policy of evacuate, never shelter, for flammable gas releases needs further study to address these issues.

## CONCLUSIONS

The new CAFC shelter vs evacuation decision flow chart gives clear guidance to first responders on the initial decision to choose shelter-in-place or evacuation as the best protective action. The decision flow chart provides the flexibility to order evacuation of the initial exclusion zone and of the larger protective action zone as shelter-in-place become less effective with time.

The tight building construction that is typical in Canada often provides at least a one hour building infiltration time constant. What this means in terms of effective shelter time requires a knowledge of the release rate of the toxic gas, and the dispersive ability of the atmosphere between the release point and the shelter building.

The definition of Aadequate protection from shelter-in-place@ needs to be refined by training of first responders and by documenting their experience in actual incidents. This information will give the incident commander a clear idea whether shelter-in-place is still Aeffective@, and in particular, Ahow effective@.

First responders should exploit these bubbles of clean air inside buildings as an alternative to forcing people into a potentially hazardous outdoor exposure during evacuation.

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